Meeting report of the first research coordination meeting (RCM) of coordinated research project (CRP) on small reactors without on-site refuelling (CRP i25001)

IAEA, Vienna, 21 – 25 November 2005

Project officer: V. Kuznetsov, v.v.kuznetsov@iaea.org

1. Objectives of the meeting

The first Research Coordination Meeting (RCM) of a Coordinated Research Project (CRP) on Small reactors without on-site refuelling was held on 21- 25 November 2005 in Vienna with 19 participants and observers from the involved 18 research institutes and organizations of Brazil, Croatia, India, Indonesia, Italy, Japan, Lithuania, Morocco, the Russian Federation, the United States of America, and Vietnam, and had the following main objectives:

(1) To review the progress achieved during the first year of the project in the activities on:

- Identification and prioritisation of the enabling technologies, concepts and designs of Small Reactors without On-Site Refuelling;
- Definition of the scope of requirements and broader specifications for Small Reactors without On-Site Refuelling;
- Elaboration of technical and regulatory approaches to revise the need for relocation and evacuation measures (unique to NPPs with innovative SMRs);
- Review of the approaches to ensure lifetime core operation without refuelling and define the scope of benchmark analysis for long-life cores of several reactors;

(2) To establish collaboration in further activities on:

- Identification of requirements and broader specifications for NPPs with Small Reactors without On-Site Refuelling for selected representative regions;
- Elaboration of technical and regulatory approaches to revise the need for relocation and evacuation measures (a continued activity); and
- Benchmark analysis of long-life cores of several concepts of Small Reactors without On-Site Refuelling; identification of further necessary R&D;
- Review of passive safety design options for such reactors and identification of accident scenarios, passive reactivity regulating systems, and passive decay heat removal systems for comparative analysis.

2. Scope of the meeting

The Agenda of the meeting and the list of participants are enclosed as ANNEX I and ANNEX II respectively.

First year reports from participants were presented and discussed; the collection of first year reports, presentations and materials submitted to the meeting is available upon request from the office of the project officer, V. Kuznetsov at: v.v.kuznetsov@iaea.org. The progress of all participants was rated as good.

The CRP has three distinct tasks and groups of participants; therefore, the meeting included dedicated discussions, brainstorming and writing sessions in the groups. The major findings of these sessions, presenting the structure, the participants, the background, the scope, the objective and the status of activities within groups, and providing the plans of coordinated research for the next year and beyond are summarized as the following.

3. Major findings

3.1. Group 1 "Revising the need for relocation and evacuation measures unique to NPPs with innovative SMRs"

3.1.1. Participating organizations

The activities of Group 1 within the CRP involve five organizations from five Member States:
(1) Westinghouse (USA);
(2) FER, Zagreb University (Croatia);
(3) Politecnico di Milano – POLIMI (Italy);
(4) Eletronuclear (Brazil);
(5) Lithuanian Energy Institute – LEI (Lithuania).

3.1.2. Leader of Group 1

The leader of Group 1 is Mr. Mario Carelli; when unavailable – Mr. B. Petrovic (both from Westinghouse, USA).

3.1.3. Background

Elimination of Emergency Planning Zone (EPZ) is one of the goals of INPRO. In IAEA-TECDOC-1434 user requirement 1.5 in the area of safety suggests that innovative nuclear energy systems (INS) "shall not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility". The corresponding criterion is specified as "probability of large release of radioactive materials to the environment"; and the acceptance limit considered is "$<10^{-6}$ per plant-year, or excluded by design".

INPRO appears first to state "the end point should be…to make the risk of INS comparable to that of industrial facilities used for similar purposes, so that for INS there will be no need for relocation or evacuation measures outside the plant site".

The IAEA-TECDOC-1434 also suggests "safety analyses will involve a combination of deterministic and probabilistic assessments, including best estimate plus uncertainty analysis".

Elimination of EPZ is also a goal of GIF. One of the Generation IV safety goals reads as "no need for offsite response: no credible scenario should exist for release of radioactivity requiring offsite response to ensure public safety. This goal is not to be construed as zero probability of any accidental release; rather, the focus of this goal is to eliminate the need for formal emergency planning". A reasonable measure of this goal could be expressed as "no credible accident scenarios that could result in offsite release of radiation exceeding US protection action guidelines; …these guidelines may change as improved radiation dose-response models are developed".

Elimination of EPZ appears to be a common goal of both INPRO and Generation IV. Increased cooperation between INPRO and GIF finds a broad support from the IAEA Member States (General Conference resolutions of 2003, 2004 and 2005). Quoting from Nuclear News, Nov. 2005, pp. 53-54 (referring to innovative nuclear systems), "one target spelled out was that systems could be sited in very similar locations to those of other energy-producing systems."

The approach to revise emergency planning measures may require revising or re-interpreting regulations. Current regulations vary among Member States. They either prescribe EPZ size or are deterministic, or risk-informed, or risk-based, or appear as some combination thereof. The technical basis is not always clearly spelled out.

During discussions at the meeting, it was noted that while this activity may apply to all innovative nuclear energy systems (INS), it applies especially to SMRs because:

- They will be sited near to the customer base and may be very near the customer in the case of cogeneration, seawater desalination, and district heating missions; and
- To meet customer needs, SMRs of small heat rating have already foregone economy of scale on equipment; but in light of the small source term and extensive application of

passive safety features they should not have to suffer loss of economy of scale in siting requirements as well.

3.1.4. Task description and objective

The task of Group 1 within the CRP is to develop a methodology and to identify regulatory approaches to revise (reduce or eliminate) off-site emergency measures such as evacuation and relocation for NPPs with innovative reactors. The revision of off-site emergency planning is a stated objective of INPRO and GIF. Specifically for innovative SMRs it may be a necessary condition for their competitive deployment.

The general objective of Group 1 activities assumes there may be several equivalent, similar, or related practical implementations, such as to:

- Eliminate the need for off-site response;
- Revise the need for off-site relocation and evacuation measures;
- Reduce the size of the emergency planning zone (EPZ);
- Possibly, reduce the EPZ to fit within site limits (thus eliminating the off-site response); etc.

It is recognized that while the complete elimination of off-site EPZ may be difficult, eliminating or even reducing most costly measures may provide similar economic effects/benefits.

3.1.5. Participants of the RCM

For Group 1, the participants of the meeting were:
(1) Bojan Petrovic (Westinghouse, USA);
(2) Nikola Cavlina, Chairman of the sessions of Group 1 (FER, Zagreb University, Croatia);
(3) Andrea Maioli (POLIMI, Italy);
(4) Fernando Henning (Eletronuclear, Brazil);
(5) Juozas Augutis (LEI, Lithuania);
(6) Davor Grgic, Observer at the meeting (FER, Zagreb University)

3.1.6. Status of activities

The overall approach of Group 1 is to develop a technology-neutral, integrated, risk-informed methodology to evaluate advanced NPPs and, on its basis, to derive adequate EPZ size and new or revised emergency planning measures. It is noted that such methodology is:

- Easier to implement in regulations that already have a risk-informed or risk-based component;
- More challenging to implement when the regulation is prescriptive.

First project year has been successfully completed; the second year is starting. The focus of the ongoing activities is on:

- Reviewing current regulations;
- Developing a technology-neutral, risk-informed approach;
- Evaluating the resulting economics benefits.

The coordination within Group 1 was well established within the first year of works.

3.1.7. Plan for the second year

The plan for the 2nd year of the CRP is as follows:

Westinghouse (USA):

- Continue work on the overall approach and methodology; support POLIMI/FER analyses;
- Present/discuss the proposed revision in the USA; interact with the US NRC and EPRI;

POLIMI (Italy):

- Continue development of integrated, risk-informed methodology;
- Continue PRA analyses to refine classification of relevant accident sequences;

FER (Croatia):

- Continue development of deterministic models for IRIS severe accident (SA) sequences;
- Perform and refine analyses of SA sequences;

LEI (Lithuania):

- Prepare meteorological data for a typical European location;
- Continue evaluation of benefits of reduced EPZ for district heating applications;

Eletronuclear (Brazil):

- Evaluate capital cost (infrastructure cost) and O&M cost (emergency planning cost) of EPZ for the Angra site in Brazil;
- Evaluate benefits of reduced EPZ for desalination applications.

3.1.8. Possible contributions from other participants

The areas of potential contribution from additional members of the group could be most beneficial in the areas of regulations and cost-effectiveness. Specifically, participants from other Member States are invited to provide answers to the following questions:

- What is current national regulation for EPZ? What is the technical basis?
- What is the licensing basis (deterministic, risk-based, or risk-informed)? What is the current use of PRA level 1-2-3 in licensing?
- Is there a constituency and interest to revise EPZ regulation? From whom? When?
- What are the motivations and perceived benefits?
- What are most probable objections, resistances, and roadblocks? From whom?

3.1.9. TECDOCs to be prepared

Group 1 plans to prepare one TECDOC summarizing the final outputs of their study at the end of this CRP.

3.2. Group 2 "Design and technology development for LWRs with coated particle based fuel"

3.2.1. Participating organizations

The activities of Group 2 within the CRP involve seven organizations from six Member States:
(1) PNNL (USA);
(2) VNIIAM (the Russian Federation);
(3) RRC KI (the Russian Federation);
(4) Hokkaido University (Japan);
(5) Federal University of Rio Grande do Sul (Brazil);
(6) Mohammed V University (Morocco);
(7) INST (Vietnam).

3.2.2. Leader of Group 2

The leader of Group 2 as elected during the RCM is Mr. G. Tsiklauri (PNNL, USA).

3.2.3. Background

Concepts of small reactors with coated particle based fuel are being considered in the USA (AFPR-100), the Russian Federation (BWR-PB), Japan (PFPWR50) and Brazil (FBNR) to achieve enhanced protection against human actions of malevolent character, enhanced proliferation resistance, to eliminate radiological consequences of severe accidents and achieve reduced complexity of the overall plant design. Such reactors target non-electrical applications, such as district heating or potable water production, that benefit from the NPP being located in the immediate vicinity of the customer. Their sound and transparent safety concept is considered as a factor to improve public acceptance.

The ceramic-coated particle fuel for the LWRs might be not encapsulated (AFPR-100, BWR-PB) or encapsulated in the matrix material, e.g., graphite or SiC. When coated particles are not encapsulated, they are called micro fuel elements (MFE) and, different from the fuel of high temperature gas cooled reactors, use SiC or other but not pyro-carbon outer coating layer. The US (AFPR-100) and Russian (BWR-PB) concepts use coated particles directly, while the Japanese concept (PFPWR50) puts the particles within a graphite matrix into cylindrical tubes made of Zircaloy, and the Brazilian concept (FBNR) compacts the particles into 15 mm diameter spheres similar to that of German / South African high temperature gas cooled reactors (HTGRs) but cladded by SiC.

This design of MFE has extremely important benefits for reactor safety. Strong negative coolant and void reactivity coefficients combined with a very short thermal delay time (< 0.01 s) allow the reactor to shutdown quickly in the event of a malevolent human action such as a premeditated reactivity or power excursion.

The heat transfer surface area is larger by several orders of magnitude than in standard fuel rod assemblies of LWR due to the small spherical dimensions of the MFE. Therefore, the normal operating temperature of fuel is low (about 300°C for BWR and not more than 600°C for the supercritical water pressure reactor coolant temperature). Small diameter of the fuel kernel and large heat exchange surface of MFE significantly lowers the fuel peak temperatures, minimizing heat energy stored in the fuel and eliminating heat exchange crisis. The larger heat exchange surface significantly simplifies residual heat removal by natural convection and radiation from the core to a subsequent passive heat removal system.

The critical issue for reactor concepts in this category is corrosion of outer coating layers, e.g., SiC, in high temperature and high pressure water and steam as well as their performance under irradiation.

Russian organizations (RRC "Kurchatov Institute", VNIIAM, LUCH) have extensive data on corrosion and erosion of SiC in water and steam and under irradiation. The conclusion is that SiC is a corrosion resistant coating for nuclear fuel;

There are some conflicting data on SiC corrosion, such as obtained in the tests performed in the Republic of Korea (2003); Oak Ridge National Laboratory and Pennsylvania State University (1995-2001), which demonstrated increasing corrosion with water and steam pressure.

3.2.4. Task description and objective

As all reactors in this group are at a pre-conceptual or early conceptual design stage, the general objective is to validate key enabling technologies for such reactors. The specific tasks include studies of SiC corrosion, optimization of coated particle size, retrieval of data on the achievable burn-up and fluence of coated particle fuel in LWR conditions, benchmark calculations to validate neutronic and thermal-hydraulic codes, and planning and performance of necessary tests.

3.2.5. Participants of the RCM

For Group 2, the participants of the meeting were:

(1) G. Tsiklauri, Chairman for Group 2 (PNNL, USA);
(2) E. Grishanin (VNIIAM-RRC KI, Russia);
(3) Y. Shimazu (Hokkaido University, Japan);

(4) F. Sefidvash (Federal University of Rio Grande do Sul, Brazil);
(5) L. Erradi (Mohammed V University, Morocco);
(6) Ha Van Thong (INST, Vietnam).

3.2.6. Status of activities

Work plans have been successfully fulfilled and progress reports submitted by all participants of Group 2 who finalized their first year of work by the time of this meeting.
Coordination of further works was defined during the meeting and will be elaborated after the meeting through communication of all participants.

3.2.7. Plan for the second year and beyond

(1) Studies of SiC corrosion, including:

- Collection of the available test data on the interaction of SiC with water; specifically, retrieval of data on water-chemistry regimes and fabrication conditions of samples used in different tests would be helpful;
- Planning of an international benchmark experiment on SiC corrosion in high temperature and high pressure water; options for the exchange of samples used in previous tests could be examined also;

(2) Optimization of coated particle size, including:

- Optimization of the size of the coated particles with account of fabrication technology and neutronic analysis. What is the maximum size of a micro fuel element that could be manufactured using the available fabrication technologies?

(3) Retrieval of data on the achievable burn-up and fluence of coated particle fuel

- Collect the available data on the achievable burn-up and maximum fluence for coated particles in a range of parameters typical for LWRs;

(4) Benchmark calculations

- Development of numerical tests and verification of codes for pebble bed neutronics and thermal-hydraulics. In the first stage, a simplified data on each reactor concept is to be prepared for preliminary calculations and comparison. Specifically, double heterogeneity treatment is to be analyzed through this benchmarking;

(5) Planning and performance of a critical experiment

- To plan and perform tests of coated particles in a light water test reactor. Options to perform such tests in the MIR reactor (Dimitrovgrad, the Russian Federation) or in a test loop of the IVV-2 reactor (Ekaterinburg, the Russian Federation) should be examined.

3.2.8. Possible contributions from other participants

Not requested.

3.2.9. TECDOCs to be prepared

Group 2 plans to publish a TECDOC in 2007. The tentative structure of a TECDOC and the schedule of its preparation are as follows.

TECDOC title: "Design and Technology Development for Small Water Cooled Reactors with Coated Particle Based Fuel"

Chapter I. Short description of the four concepts of small water cooled reactors with coated particle fuel.

- Chapter 1 will based on the first-year CRP reports from Russia, the USA, Japan and Brazil.

Deadline to prepare the draft: June 2006

Chapter II. Specification of numerical benchmarks, identification of codes for benchmarking and calculations of simple models of coated particle fuel cell in steam –water coolant. Analysis and comparison of the results

The leader of this activity is Prof. Y. Shimazu,
Hokkaido University, Japan

Deadline to prepare the draft: March 2006

Chapter III. Benchmark calculations for the whole core for selected concepts, models and codes. The results will be presented during the next RCM

The leader for this optional activity is Prof. L. ERRADI
Mohammed V University, Morocco

The data should be provided by June 2006.

Chapter IV. Benchmark experiment on the corrosion of SiC in high pressure and high temperature water and steam. Participants from Group 2 will provide samples of SiC-coated fuel elements (or mock-ups). Possible experimental facilities are those of VNIIAM and a critical test reactor "ASTRA" of the RRC "Kurchatov Institute". The support from IAEA could be requested.

The leader of this activity is Dr. E. Grishanin

Deadline to complete planning of tests: October 2006

Chapter V. •Optimization of coated particle size taking into account fabrication technology and the results of neutronic analysis. What is the maximum size of a micro fuel element that could be manufactured using the available fabrication technologies?

The leader of this activity is Dr. G. Tsiklauri
Deadline to prepare the draft: October 2006

Chapter VI. The available data on maximum achievable burn-up and fluence for coated particles in a range of parameters characteristic of LWRs.

The leader of this activity is Dr. E. Grishanin
Deadline to prepare the draft: October 2006

3.3. Group 3 "Design and technology development for lead, lead-bismuth, and molten salt cooled reactors"

3.3.1. Participating organizations

The activities of Group 3 within the CRP involve seven organizations from five Member States:
(1) IPPE (The Russian Federation)
(2) Tokyo Tech (Japan)
(3) ANL (USA)
(4) ITB (Indonesia)
(5) EDO Gidropress (The Russian Federation)
(6) RRC "Kurchatov Institute" (The Russian Federation)
(7) BARC (India)

3.3.2. Leader of Group 3

Group 3 includes the design teams for Pb, Pb-Bi, and molten salt cooled reactors of fast and intermediate neutron spectrum. The leader of Group 3 as elected during the RCM is Mr. I.V. Dulera (BARC, India).

3.3.3. Background

The Russian Federation has vast experience with different aspects of lead/lead-bismuth coolant and lead/lead-bismuth cooled small reactors.

In the beginning of 1950s the USSR started development of reactor installations (RI) with lead-bismuth coolant (LBC) for nuclear submarines. Eight nuclear submarines were constructed in the USSR in total with the RI using LBC. Two full-scale ground-based LBC reactor prototypes were constructed and operated for carrying out various tests. The total operating experience of the RI with LBC exceeds 80 reactor-years.

In the course of design and operation of the lead-bismuth cooled reactor installations for nuclear submarines, a large number of the design and technology development problems have been solved and all major aspects of the LBC technology have been mastered. Several examples are given below:

- Technologies were developed to control/prevent the corrosion of structural materials. These include maintaining and controlling the LBC quality and controlling the mass-transfer processes in the reactor circuit,
- Methodologies and procedures have been established to ensure radiation safety of the personnel involved in operation, maintenance and refuelling of the reactor installation, incorporating the equipment contaminated with Polonium-210;
- Problems associated with lead-bismuth expansion during solidification were addressed and multiple operations with coolant “freezing-unfreezing” in the LBC reactor installation were demonstrated.

The Russian experience has been made public through open literature published in the mid 1990s and a historic international conference in Obninsk (the Russian Federation) held in 1998.

The important features of Pb, Pb-Bi as well as molten salt cooled reactors are:

- Due to a broad available operating temperature range (from slightly above the melting point to more than 1000^{o}C), the reactors based on these coolants can be used for hydrogen production as well electricity generation; combined heat and power (CHP) mode of operation with the use of the reject heat for district heating/ seawater desalination is possible;
- Various concepts of thermal and fast spectrum reactors are possible with these coolants;
- Such reactors are well suited for different kinds of fuel and fuel cycles, including ^{235}U, Pu, and ^{233}U based fuel cycles using metallic, oxide, carbide or nitride fuel, as well as HTGR type TRISO coated particle fuel.

Several features related to the inertness and high boiling point of lead and LBC coolant, negative temperature coefficients and other favourable feedback characteristics of lead and lead-bismuth cooled reactors make them attractive from the safety point of view.

In the Russian Federation, EDO Gidropress and IPPE have developed basic designs of small lead-bismuth cooled reactors SVBR-10 and SVBR-75/100 for multi-purpose use. The initial versions of these designs essentially reproduce the design and technology features of the former reactor installations of nuclear submarines, but they differ by the fast neutron spectrum and integral design of the primary circuit.

In the Russian Federation, RRC “Kurchatov Institute” is developing a pebble bed molten salt cooled reactor MARS.

GIF has selected energy systems with lead or lead-bismuth cooled reactors as one of the six Generation IV energy systems. Specifically, the concepts of STAR lead cooled reactors are under development or consideration (SSTAR, STAR-LM, and STAR-H2) with SSTAR being supported under a US DOE Generation IV programme. More advanced designs of the STAR family, e.g., STAR-H2, target high temperature process heat applications and provide for a research on advanced structural materials such as SiC – SiC based composites and other ceramics.

In Japan, the Tokyo Tech is developing a concept based on direct contact LBC cooled boiling water reactor (PBWFR) and is carrying out the related test programme to study the thermal-hydraulics of such 'combined' coolant system. Tokyo Tech is also performing tests related to the polonium problem and also has studied intensively the ADS based systems obtaining many new and important results. Material erosion and corrosion related studies have also been conducted.

In India, BARC is developing the conceptual design of a compact nuclear power pack, which is a thermal reactor with ^{233}U-Th metallic fuel, BeO moderator, and lead-bismuth coolant. The reactor under development will incorporate passive safety features and, specifically, passive heat removal in all operation modes. The use TRISO coated particle based fuel is also being explored as an option.

In Indonesia, ITB is developing concepts of small and very small LBC reactors, SPINNOR and VSPINNOR with "zero" burn-up core and optimized reactivity feedbacks.
Many institutes in Member States such as the Russian Federation, Japan, the USA, Indonesia, India, and the Republic of Korea have shown interest in the coordinated work on small lead, LBC and molten salt cooled reactors.

3.3.4. Task description and the objective
The general objective of the activities of Group 3 is to collect available data on properties of lead, lead-bismuth and molten salt coolants, as used by different design teams, and to compile a handbook of those properties of these coolants that are important for the neutronics and thermal hydraulics calculations of the relevant small reactors. The specific tasks include benchmark analysis of the neutronic and thermal-hydraulic characteristics of proposed models. Future work will also include safety and sensitivity analyses (for safety related studies). Also included are works related to the development of several enabling technologies, such as material compatibility studies, studies for coolant purification technologies and development of special components related to these coolants.

3.3.5. Participants of the RCM
For Group 3, the participants of the meeting were:
G.I. Toshinsky (IPPE, the Russian Federation);
H. Sekimoto (Tokyo Tech, Japan);
D. Wade (ANL, USA);
Zaki Su'ud (ITB, Indonesia);
A. Dedul (EDO Gidropress, the Russian Federation);
A. Sedov (RRC "Kurchatov Institute", the Russian Federation);
I.V. Dulera, Chairman of Group 3 (BARC, India).

3.3.6. Status of activities
Work plans have been successfully fulfilled and first-year reports submitted by the participants of Group 3 who completed their first year of work by the time of this meeting.

Coordination for future work was defined during the meeting and will be elaborated after the meeting through communication of all participants.

3.3.7. Plan for the second year and beyond

The activities to be performed within the next year are as follows:

- Development of a consolidated database related to the neutronic and thermo-physical properties of Pb, LBC and molten salt. The database also aims to include results of various material compatibility studies and thermal-hydraulic correlations at different temperatures (up to 1000^{o}C).
  To initiate this activity, a mutually agreed format will be prepared under the guidance of Dr. David Wade (ANL, USA); the possibility of accessing a similar database being developed at the OECD/NEA will also be examined; the initial effort would be to compile data from all relevant sources; BARC (India) would carry out translation work for literature available in Russian to English;
- Reactor physics analysis as a benchmarking exercise for two mutually agreed reactor concepts (reactors based on fast neutron spectrum and on intermediate neutron energy spectrum) with the exchange of information on codes and methodologies used for the analysis. For this, the reactor specifications will be decided with mutual agreement through further correspondence;
- Thermal-hydraulic analysis (specifically, for natural circulation) as a benchmarking exercise for a mutually agreed reactor/ loop concept(s) with the exchange of information on codes and methodologies used for the analysis; the reactor/ loop specifications to be decided with mutual agreement through further correspondence.

Additional activities for next two years would be:

- Structural material compatibility studies with these coolants for the extended temperature ranges (up to 1000^{o}C) – for metals, carbon, ceramics, coatings; and exchange of data for the same;
- Studies of general behaviour of the coolants during planned/ unplanned “freezing-de-freezing” due to reactor returning to cold conditions;
- Studies of natural circulation behaviour of coolant with and without assistance of the injection of gas or water;
- Development of the enabling technologies related to lead, lead-bismuth and molten salt coolants. This includes:
  - Development of primary components, instrumentation and sensors, such as centrifugal and electromagnetic (EM) pumps, EM flow meters, oxygen sensors, sensors to monitor Pb as well as Po activity in the environment;
  - Corrosion control technologies;
  - Purification technologies (to remove corrosion products and polonium, etc.)
- Safety analysis under postulated accident scenarios;
- Sensitivity analysis for the neutronics and safety related studies.

Schedule for the activities in 2006

(I) Exchange of data on Pb, Pb-Bi and molten salt thermo-physical characteristics as well as exchange of information on the used computer codes would be the first step towards the compilation of a handbook.

The data on the properties, among others, would include:

(a) Data used for the neutronic calculations of Pb, Pb-Bi, and molten salt cooled reactors (variation with respect to temperature up to 1000^{o}C or more);

(b) Data used for thermo-hydraulic calculations of Pb, Pb-Bi, and molten salt cooled reactors (variation with respect to temperature up to 1000^{o}C or more);

(c) Heat transfer correlations and coefficients;

(d) Compatibility data for structural materials with coolant and results of the corrosion behaviour studies;
(e) Mechanical properties of structural materials with respect to temperature and fluence;
(f) Description of the computer codes used for neutronics, thermal-hydraulics and safety analyses.

The contributors are requested to include the details of references (sources of data).

Milestones: Mid December 2005 - First suggestion of the database format by Dr. D. Wade;
End of January 2006 - Finalization of the format;
End of April 2006 - Submission of available data by participating institutions for the compilation of a handbook;
End of August 2006: - Compilation of data.

(II) Neutronics-related benchmark analysis. There will be two types of neutronic benchmarks for Pb-Bi/ Pb/ molten salt cooled systems:
- For reactors with fast neutron energy spectrum;
- For reactors with intermediate neutron energy spectrum.

Milestones: By January 2006 - First suggestion on reactor configurations;
By April 2006 – Final definition of reactor configurations;
May-early September 2006 – Calculations/ analysis of results by each design team; repeated calculations, if needed.

- Dr. Zaki Su'ud will provide the geometry, configuration and other necessary data for benchmark analysis of fast reactor systems.
- Dr. A. Sedov will provide the geometry, configuration and other necessary data for benchmark analysis of intermediate spectrum reactor systems.

The characteristics to be benchmarked are:

(a) At BOL: - Keff;
- Power distribution;
- Breeding ratio;
- Point wise isotopic reaction rates (for important nuclides: ^{238}U, ^{23}9Pu, etc.)

(b) Depletion analysis (0 ~ 30 years):
- Keff changes with depletion (0 ~ 30 years);

(c) At EOL: - Power distribution;
- Breeding ratio;
- Point wise isotopic reaction rates (for important nuclides: ^{238}U, ^{23}9Pu, etc.)

(III) Fission products analysis model

Milestone:
- Dr. Zaki Su'ud will distribute partial results of his fission products analysis model studies by April 2006.

(IV) Benchmark analysis for natural circulation of the coolant

The model selected and agreed upon by all participants of the group would give all the details necessary for carrying out analysis such as:

- Core details including overall dimensions;
- Pool or loop geometry;
- Details on heat removal path/steam generator. etc.

Attempt will be made to select a model for which experimental results are either available or can be found out experimentally.

Milestones:

- It is expected that initial suggestion regarding the model would come in January 2006;
- The model to be analysed will be decided by April 2006 after mutual exchange of information by the group members and discussions;

3.3.8. Possible contributions from other participants

Not requested.

3.3.9. TECDOCs to be prepared

Group 3 plans to prepare a TECDOC on Status of the neutronics benchmark analyses after completing the second year of work.

Based on the dynamic scenario studies of systems with reactors of different types, performed with the use of the originally developed DANESS code for material flow and economic analyses and including small reactors without on-site refuelling of the STAR type (lead cooled fast reactors), Dr. D. Wade of the ANL (USA) proposed a new task, in which many participants from other groups could cooperate. The proposal of D. Wade is as follows.

3.4. A Proposed CRP activity for 2006 - Intra regional and multi regional scenario studies of the role of small reactors without on-site refuelling (SRWOR) in sustainability

Small reactors without onsite refuelling (SRWOR) are proposed specifically to meet needs in developing countries where energy demand growth rate in coming decades will be large - leading eventually to very large nuclear deployments. The small reactor concepts include both open cycle and closed cycle approaches. In light of the potential for massive deployment over coming decades, starting with open cycle, but evolving to a mix of open and closed cycles, scenario studies can be useful to explore strategies for fissile mass flow symbioses among diverse reactor types orchestrated so as to attain an effective transition to sustainability within the finite uranium and thorium resource base.

As a follow up to the studies performed in ANL (USA) during the first year of work, several additional scenario studies were proposed during the meeting, such as to:

(1) Add diverse SRWOR types to the reactor mix in world multi-region scenarios, such as the following:
   - Early in the century deployments of water cooled SRWOR;
   - Benefits of high conversion ratio LWRs or HTGRs to increase world conversion ratio (CR);
   - Early deployments of liquid metal fast breeder reactors (LMFBRs) to raise world CR;

(2) Analyze options for intra-regional symbiosis, including:
   - Potential case study for South-East Asia region (good representation from South-East Asia is present in the CRP);

- Potential case study involving SRWOR coupled to a regional grid, e.g.,
  - Middle East Forum - MEF (Jordan, Egypt, etc. 7 nation grid); or
  - Former Soviet Union - FSU (Lithuania, etc. in a central European regional grid).

This proposal had no immediate response, but the participants agreed that D. Wade will distribute a description of the DANESS dynamic scenario code – which is available under a licensing agreement - and send out the list of data needed and the suggested list of scenarios to be considered. Members of the CRP will review with their organizations and inform Mr. Wade of their intention to participate in a scenarios study.
It was noted that scenario analysis could not be used to figure out the market share, since cost is not the only factor that would define it, but cost of energy for specified market shares could be of interest in the future. The DANESS code has already got the cost model capability; so for a reliable cost of energy assessment the reliability of cost characteristics of small reactors should be improved. It was recommended to elaborate cost estimates for the small reactors addressed, within further course of this CRP, and make a progress towards scenario analyses including economy characteristics in future years.
There was a suggestion that typical small reactors could be considered without assigning names.
It was also suggested that studies of this kind are of high value for the IAEA's INPRO project; and D. Wade had a discussion on this topic with the representatives of the INPRO International Coordinating Group (ICG) and INPRO management.

The RCM also included general discussions on topics that might be important for all participants. These discussions are summarized as the following.

3.5. General discussion between all participants and its outputs

The first topic addressed issues commonly highlighted by the utilities and designers of near-term NPPs in conjunction with small reactors without on-site refuelling, such as the need of:

- Identification and justification of approaches to ensure reliable lifetime core operation, such as in-service inspections, periodical safety compliance checks, etc.

- Analysis of approaches to eliminate on-site storage of spent fuel for cooling, e.g., remote refuelling techniques and equipment, reduced cooling periods, transportation casks, etc.;

- Analysis of issues associated with sealed reactor or whole-core load transportation from a technical and regulatory point of view.

The participants of the CRP provided certain arguments regarding these issues.
There was a suggestion that real historical data on how often in-service inspections resulted in identification of the need of repair and maintenance could be retrieved and not only for NPPs but also for conventional fossil fuelled plants. TEPCO and EDF data might be of high value here.
For reactors with multiple inherent safety features, the issue of in-service inspections of a lifetime core may be different from what it is for a large powered evolutionary reactor. For a reactor with a comprehensive set of inherent safety features the inspection and maintenance is more a question of the economy, while for present day reactors it is the issue of safety.
The EBR-II experience was mentioned, where for passive shutdown you had to confirm that reactivity feedbacks were still there after a period of operation. For EBR-II non-intrusive testing was found possible on an operating reactor.
Still, there could be a need to develop new in-service inspection methods.

One suggestion was to involve passive decay heat removal, e.g., to measure heat balance on RVACS and prove that it is still working.
It was mentioned that for STAR-LM a PhD student is currently working out as how to refuel the reactor and solidify lead during refuelling without on-site fuel storage. This information was said to be available to the CRP participants after this study is completed.
It was also mentioned that routine repair in maintenance is usually related to BOP components, such as turbine-plant components. Usually, repairs for turbine and reactor are coupled in present day reactors. Size of a specific reactor may be not so important.
Another comment was that degrading mechanisms are reactor-specific, e.g., corrosion by coolant. A counter-argument was provided that in lead-bismuth reactors corrosion is controlled on-line. Different in-service inspection mechanisms might be needed for different reactors. Perhaps, some internal diagnostic tests for operating small reactors could be developed.
One suggestion was that for first-of-a-kind reactor inspection will be inevitable, while later, if everything goes well, inspections might perhaps be reduced. For serial installations, inspections could be minimized also.
Regarding the experience of EBR-II, it was emphasized that fuel and materials testing were for 3-year core performance at high power density. The ANL is now working with Toshiba and CRIEPI to understand if these data are relevant for the 4S. However, sometimes it's temperature and time that are relevant rather than irradiation.
Regarding transportation experience, information was provided that the Indian KAMINI small reactor (thorium fuel based) was transported from Mumbai to Kalpakkam (for more than 1000 km). Mr. I.V. Dulera promised to clarify whether it was fuelled at that time and also retrieve other details.
In the US, a vessel of 700 t of one of the decommissioned reactors has been successfully moved across the country. The cranes capable to lift 500 t loads are operated successfully in industries other than nuclear.
It was suggested that if spent fuel will be stored for cooling at a site inside the sealed vessel of a reactor, there would be no increase of proliferation hazard. Mechanisms for sealing have been very advanced recently in areas other than nuclear and this experience could be applied in small reactors without on-site refuelling. For example, SVBR has no flanges in the primary circuit, only welded joints.
Regarding the first topic, the project officer would continue to collect relevant arguments, data and information on the experience from both, participants of the CRP and the IAEA sources.

The second topic discussed was related to the proposal of Dr. G.I. Toshinsky on the assessment of protection against nuclear terrorism using simple criteria, such as:

- Value of normalized radioactivity release (per 1 kW of reactor power) that may occur under given conditions; and
- Potential energy (compression energy, thermal and chemical energy) stored in the coolant, which may be released with corresponding destructive consequences in an event of the primary circuit depressurization.

Regarding this proposal, a general stance was that participants are not qualified enough to deal with this task. However, it was accepted that source term calculations might be useful, specifically in dealing with external events.
Dr. G.I. Toshinskiy was requested to provide more details of his theory on which to save: uranium or investment resources. The reply was that this theory is still qualitative, but when it is shaped up and filled with some quantitative data, the corresponding material would be distributed to the participants of the CRP.

4. Recommendations of the meeting

The recommendations of the meeting are as follows:

(1) Group leaders in communication with participants of their respective groups will finalize detailed scope and schedule of work of their groups, complete with responsibilities, intermediate deliverables and schedules, and submit them to the project officer not later than on 20 December 2005;

(2) Dr. D. Wade will prepare and distribute a more detailed description of his proposal (6) regarding a new scenario study with small reactors of different types by mid-January 2006;

(3) Project officer will develop a Web page for storage and exchange of the materials provided by the participants of the CRP (by the end of 2005);

(4) Depending on the progress of the CRP, the next RCM could be convened early in 2007, but preferably not in March 2007 (Mr. F. Henning will be unable to participate during that time);

5. Miscellaneous

During the meeting, four draft cross cutting chapters prepared for new IAEA Report on small reactors without on-site refuelling and associated tables had been distributed to participants for review and that comments; several comments were collected to be addressed for the final TECDOC preparation.